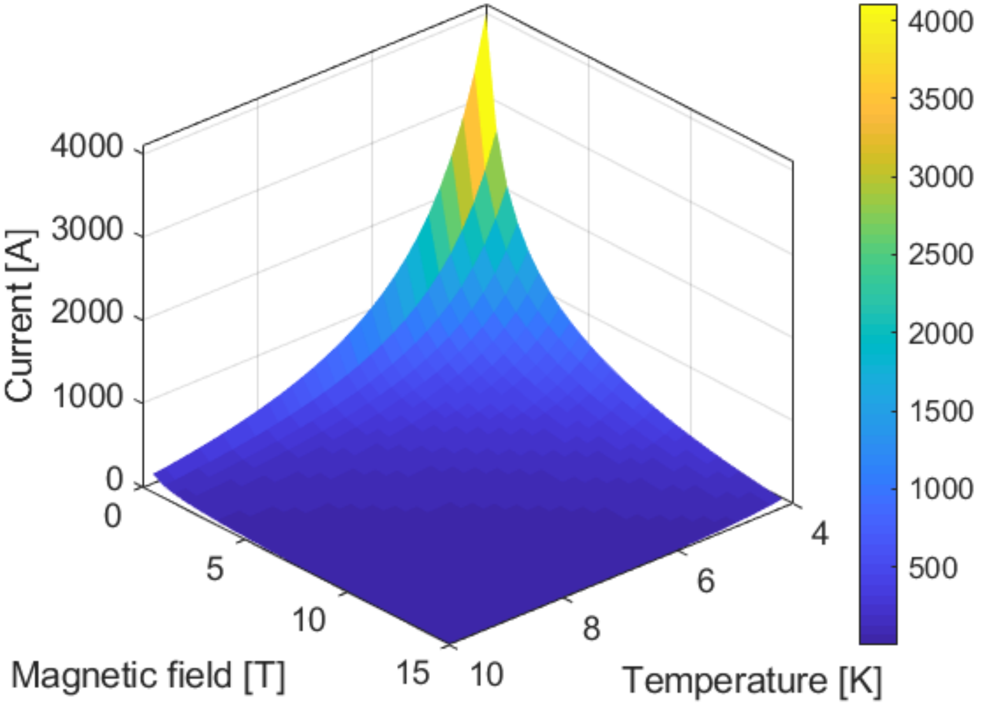
Models of High Specific Heat Nb_3Sn Wires

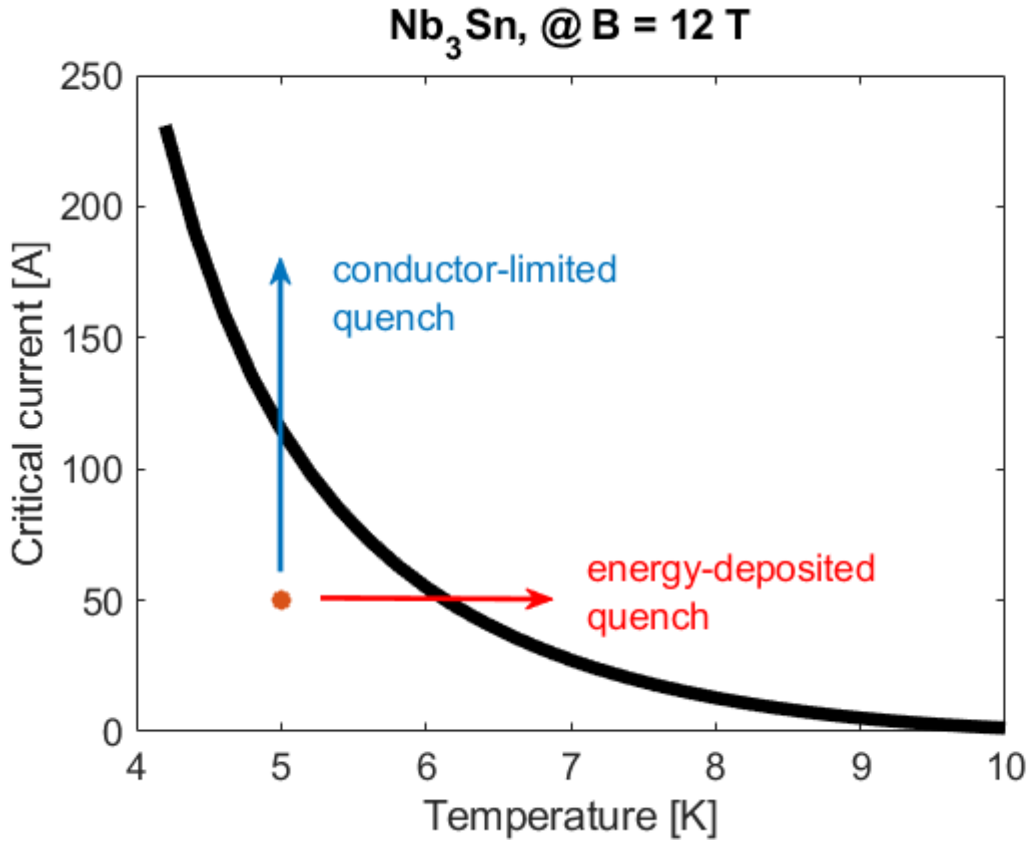
Supervisor: Alexander Zlobin Co-Supervisor: Emanuela Barzi
Summer Intern: Fabrizio Berritta
24th September 2019

Introduction

The *critical current*, *temperature* and *magnetic field* define a critical surface within which the superconducting state is sustained, i.e. non measurable resistivity and perfect diamagnetism below the critical field H_{c10}.



Introduction



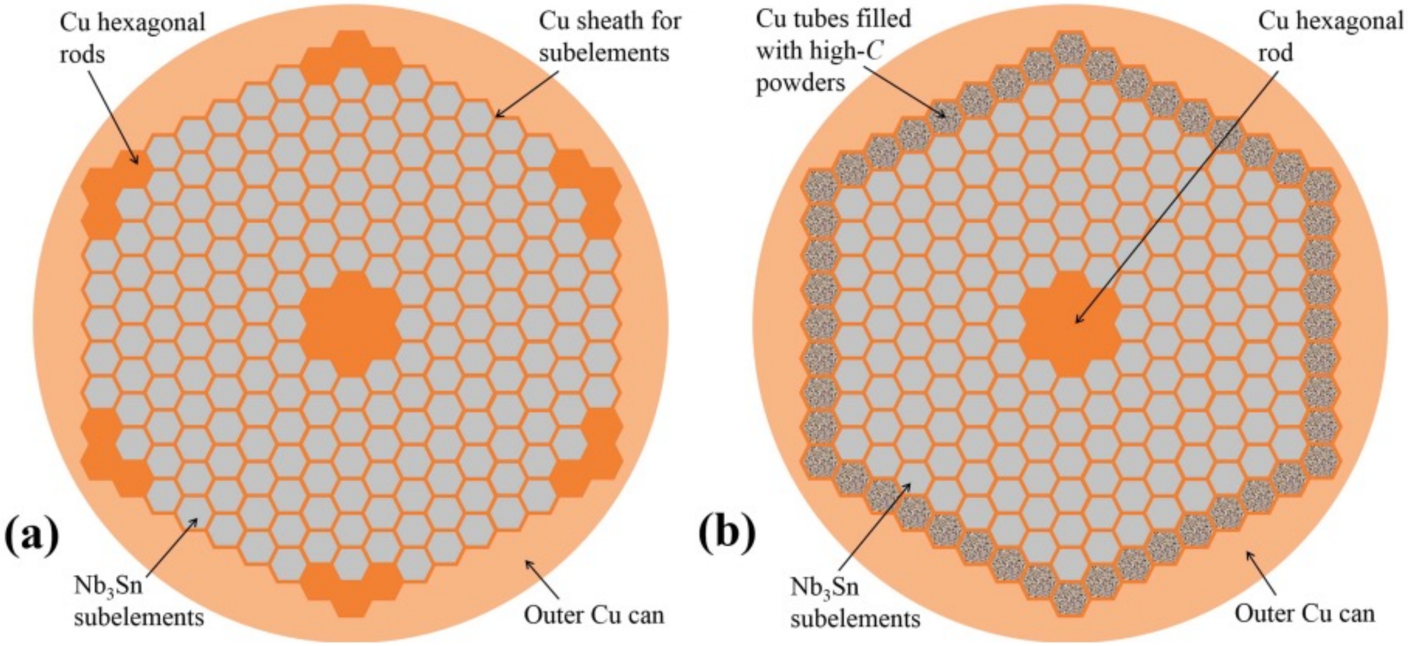
Energy Deposited Quenches

- Nb_3Sn dipole and quadrupole magnets are characterized by long trainings, since the first quenches (transition from superconducting to normal state) start at 60-70% [1] of the final limits.

- These quenches are caused by thermal perturbations due to conductor motion or epoxy cracking, etc. It is possible to reduce them by improving the wire specific heat.

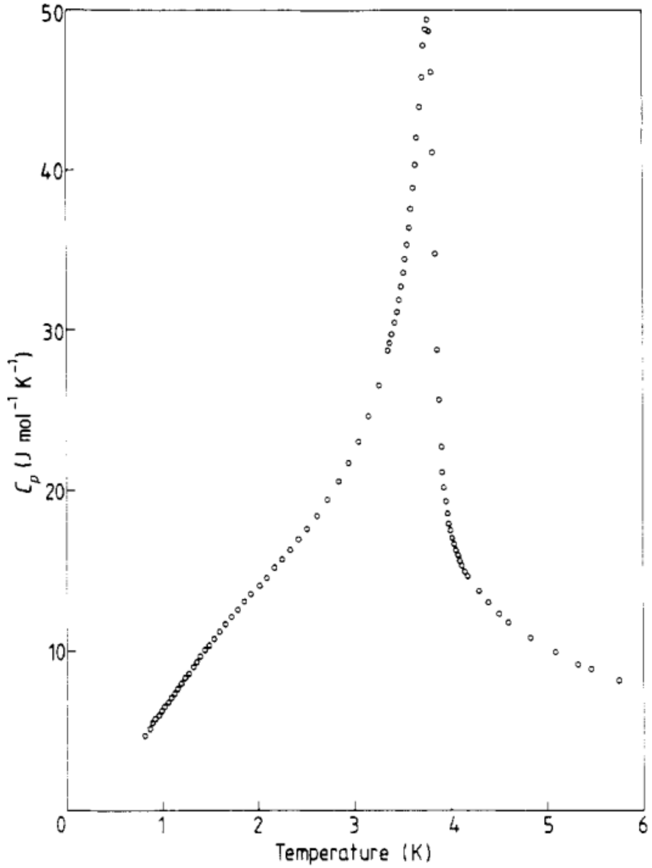
- However, high-C_p wires may break during the drawing process. The goal of this work is optimizing the High-C_p tube location for both:
  - Thermal efficiency.
  - Fabricability.

High Specific Heat Sub-elements



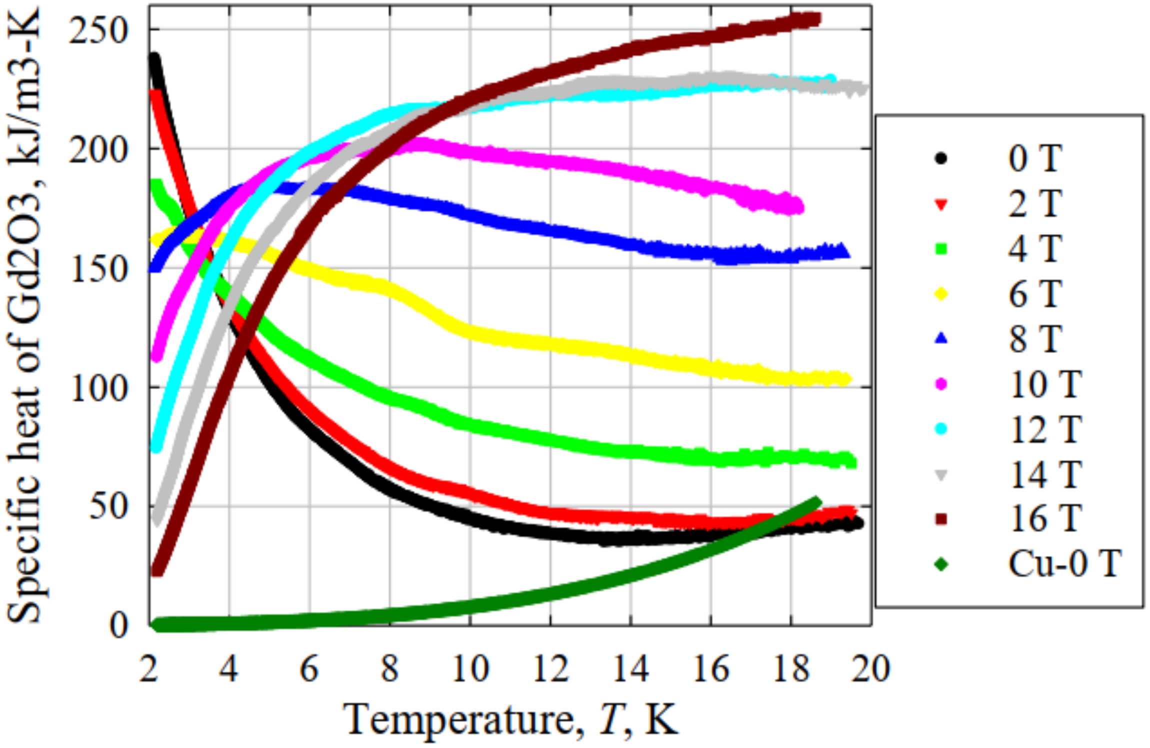
Example of cross sections of (a) a regular Nb3Sn wire and (b) a wire with high-C filaments in the outermost layer.

High Specific Heat Sub-elements



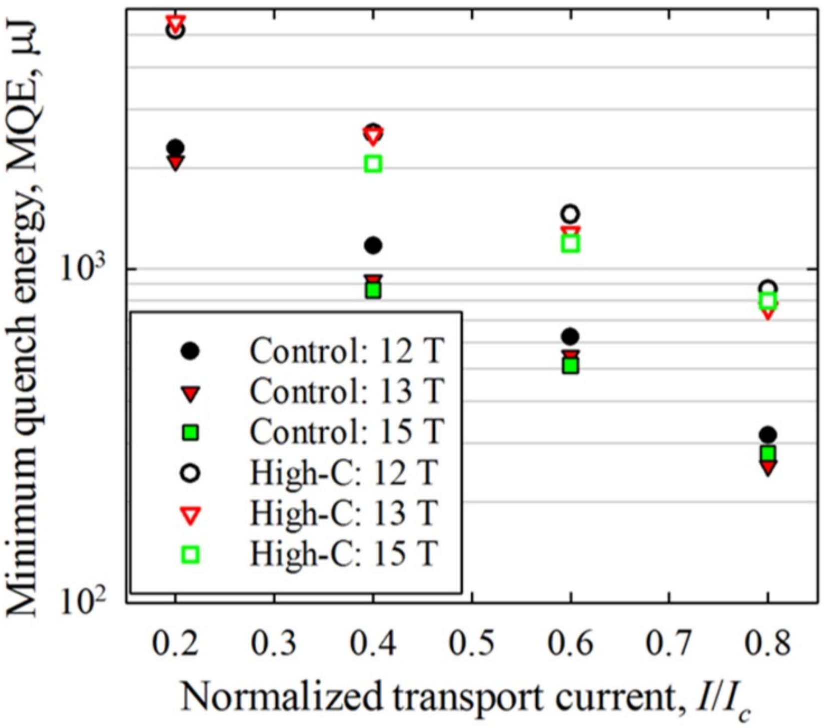
Specific heat of monoclinic Gd2O3 R. Hill et al 1983 J. Phys. C: Solid State Phys. 16 2871

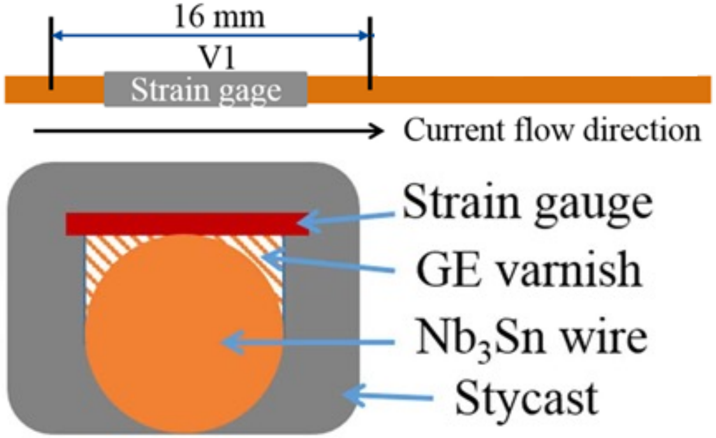
Gd_2O_3 Specific Heat @B≠0



X. Xu, A. V. Zlobin, E. Barzi – Fermilab; C. Buehler, M. Field, B. Sailer, M. Wanior, H. Miao – Bruker EST; C. Tarantini – Florida State University.
“Enhancing specific heat of Nb_3Sn conductors to improve stability and reduce training. “
Presented at **CEC-ICMC 2019.**

Experimental Setup

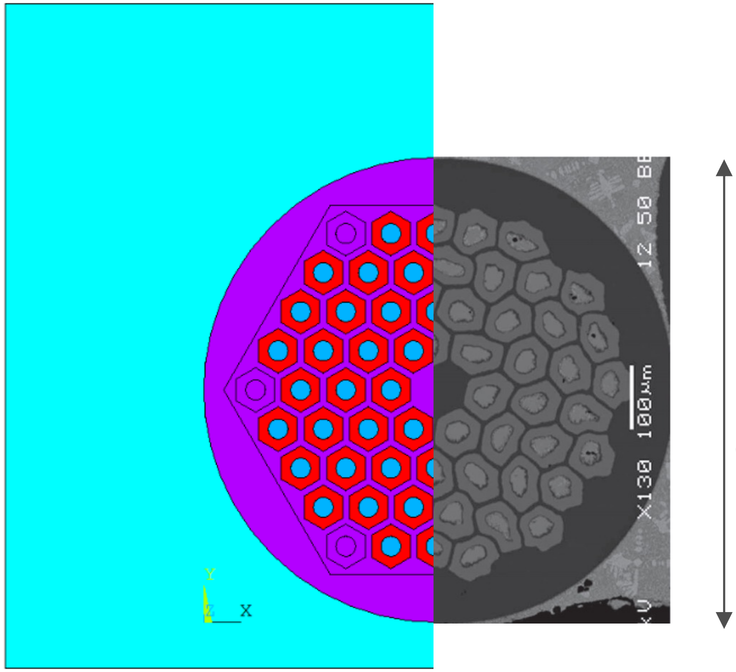




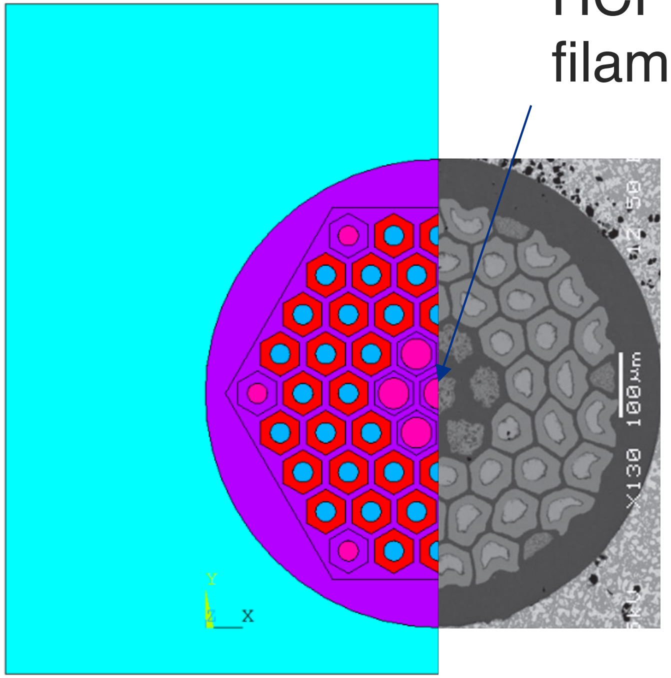
[1] Schematics of the setup to measure MQE. Xu X., Zlobin A.V. et al. "*Development and Study of Nb3Sn Wires With High Specific Heat.*"

FEM Thermal Models For ANSYS Mechanical APDL

Stycast	Cu	Nb_3Sn	Bronze	Gd_2O_3+Cu
🟦	🟪	🟥	🟦	🟪



Realized by Hypertech, 0.7 mm

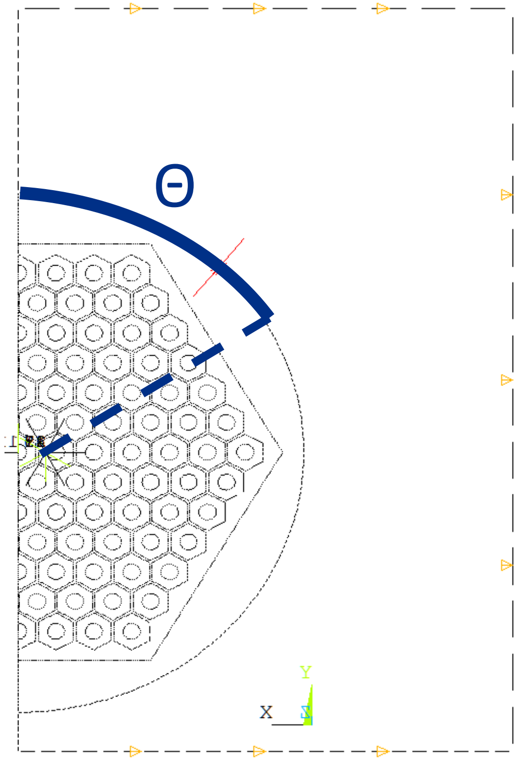


HCP tubes or filaments

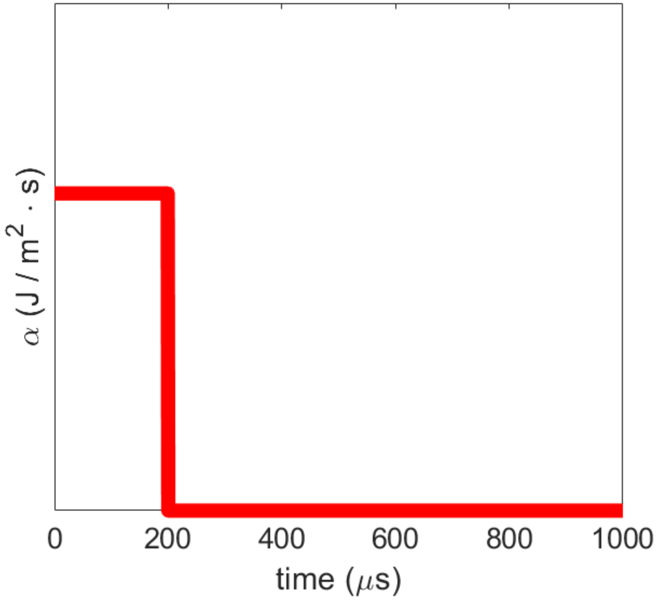
Thermal Load

The initial temperature is 4.2 K and it is set as boundary temperature constraints:

- T(**r**,0) = 4.2 K
- T(**r**,t) = 4.2 K @boundary



An heat flux pulse of 200 μs is applied on the upper half arc (2D model) with unitary thickness.



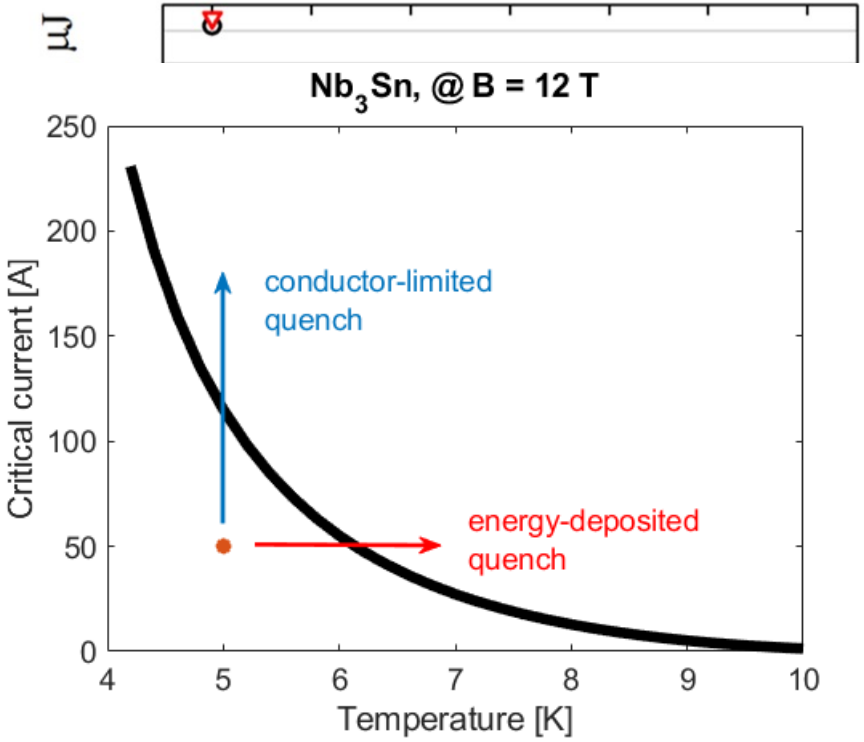
Fermilab

‘Quench’ Temperatures

$$I_c(B,T) = \frac{C}{\sqrt{B}}\left[1-\frac{B}{B_{c2}(T)}\right]^2\left[1-\left(\frac{T}{T_{c0}}\right)^2\right]^2$$

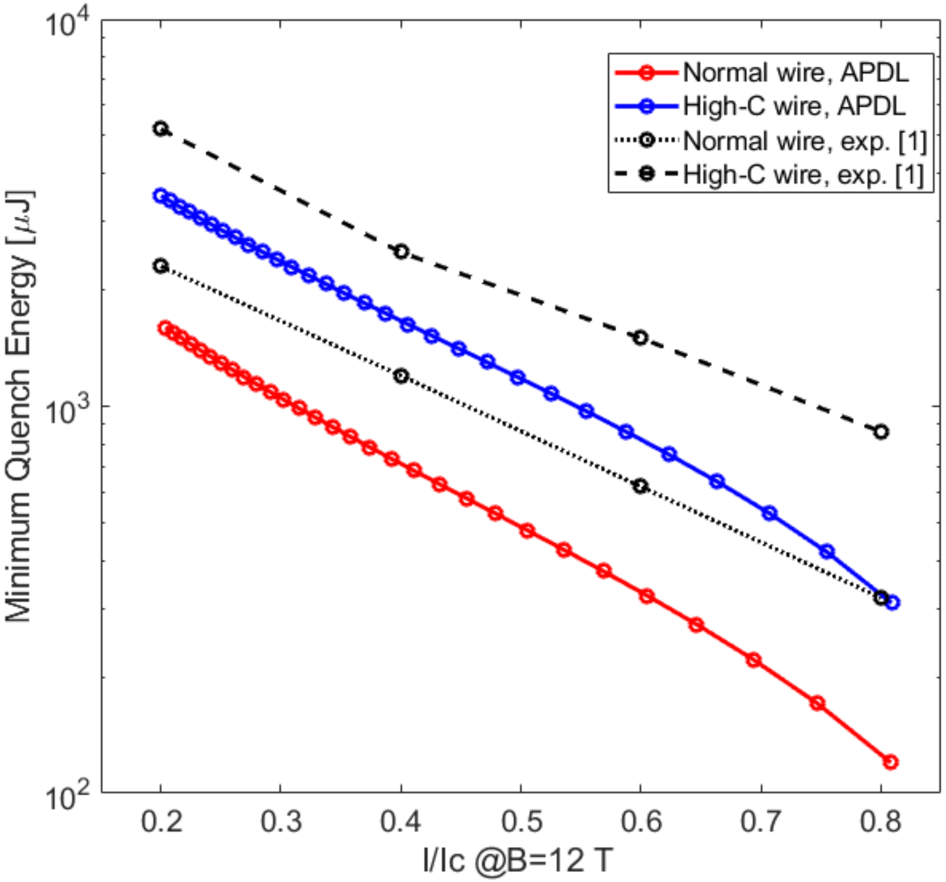
One obtains I_c(12 T, 4.2 K) and solving for T_c in I_c(12 T, T_c) the following critical temperatures:

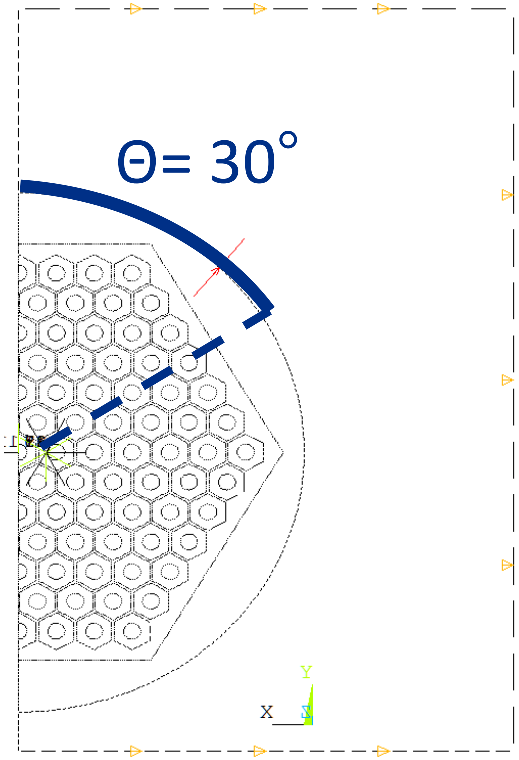
Current ratio I/I_c @B=12 T	T_c
0.2	6.3 K
0.4	5.3 K
0.6	4.8 K
0.8	4.4 K



Experimental results [1]

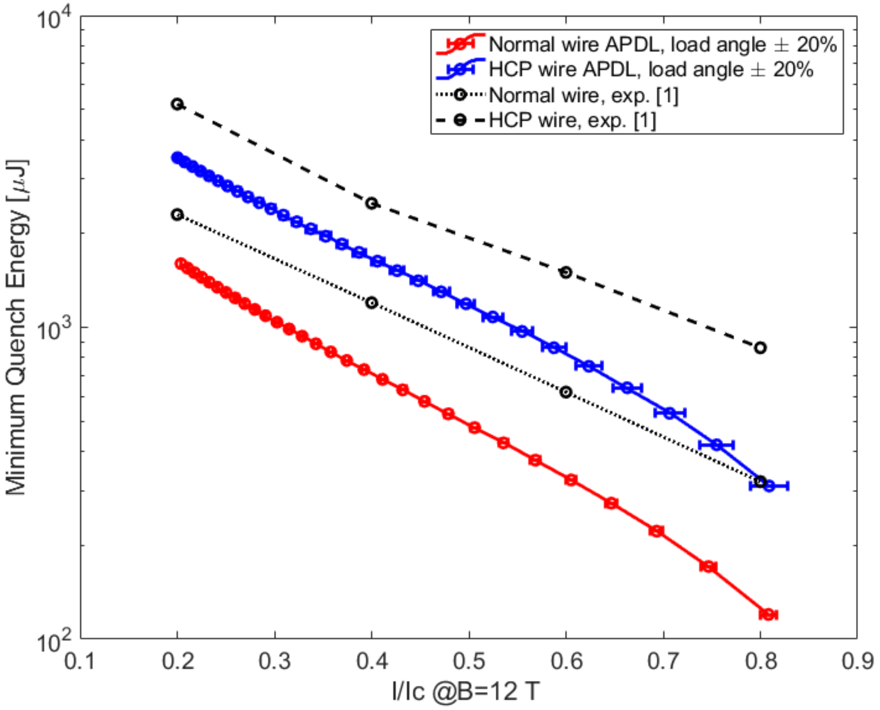
Hypertech Wires – Simulation Results

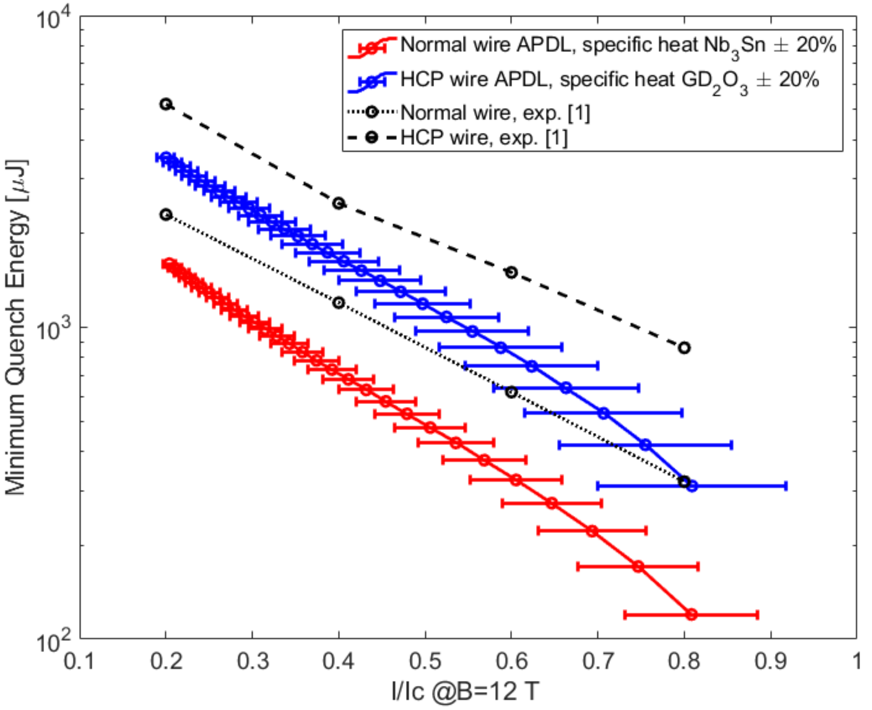




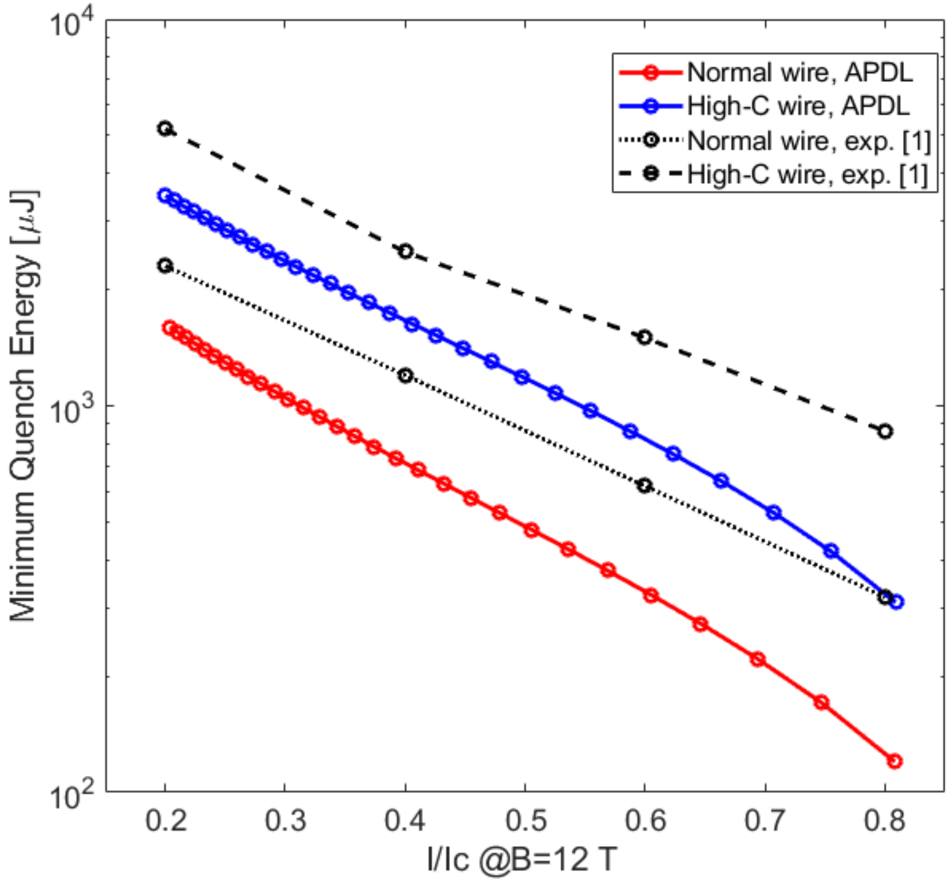
Recalling FEM model

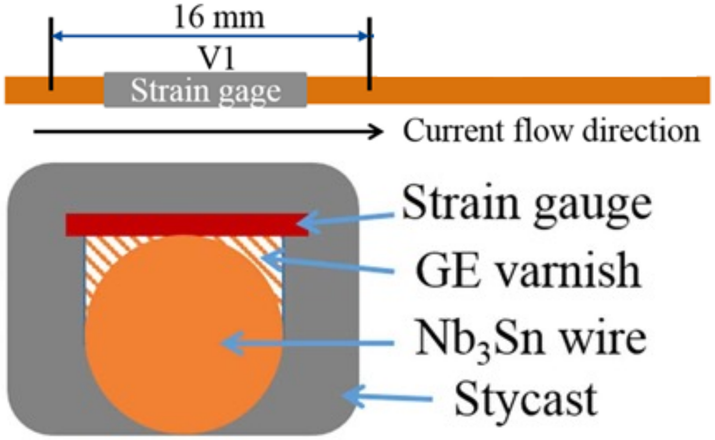
Material Properties Sensitivity





Comparing Relative Model With Experiment

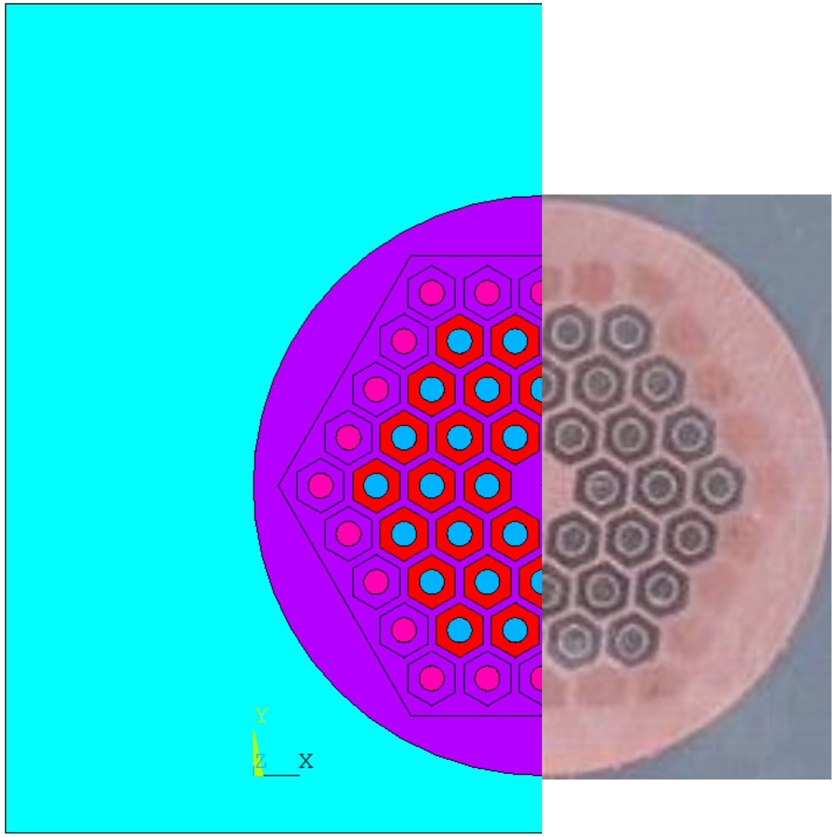




Images on top taken from [1].

Differently from the simulation, heat propagates in all directions and no volume effects (e.g. Minimum Propagation Zone) are considered.

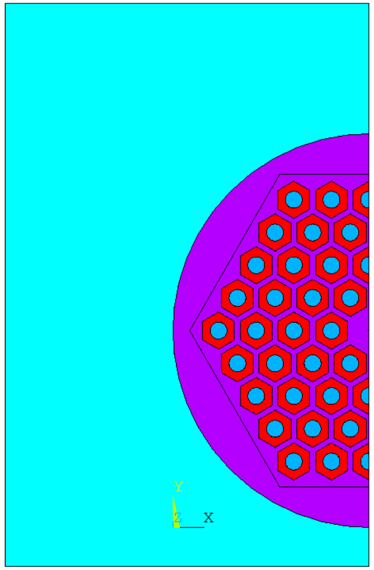
Is there an optimal thermal location for high-C elements?



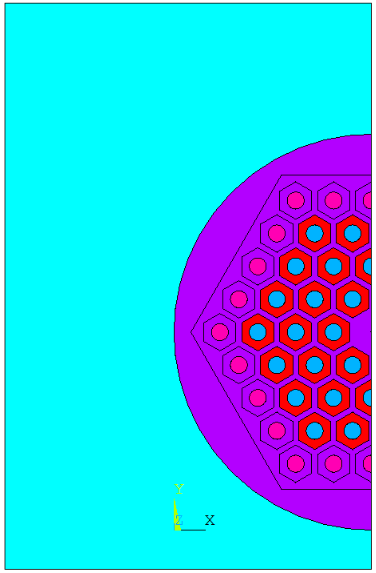
Bruker Wire Geometry, diameter 0.75”.

Drawing failure at approx. 0.162”.

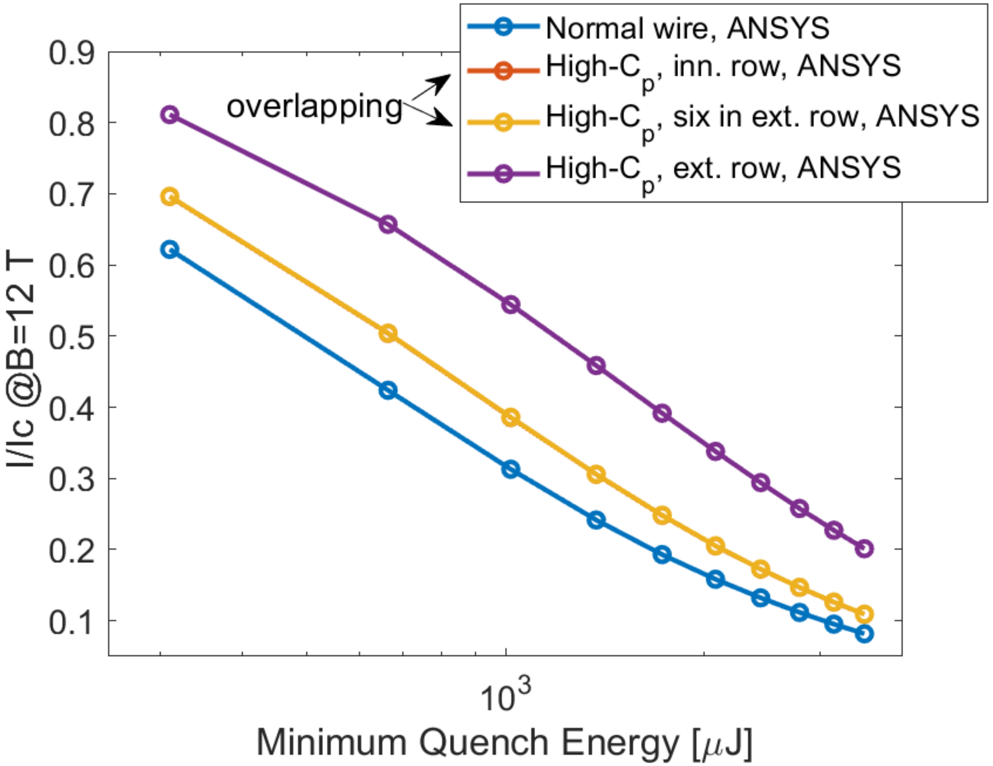
Is there an optimal thermal location for high-C elements?



Normal

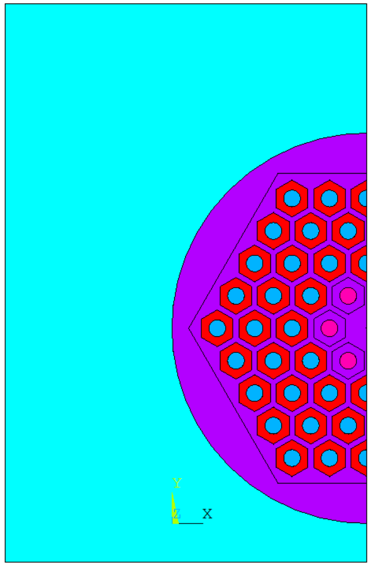


High-C, ext.row

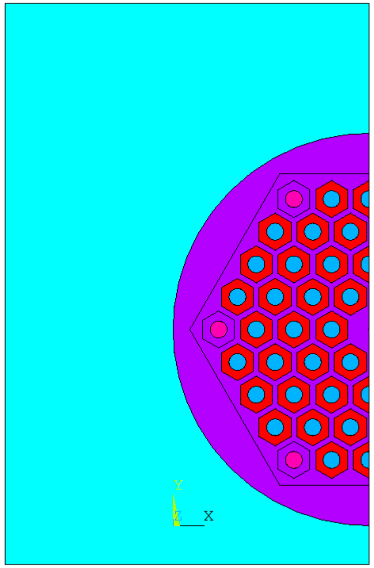


As expected, the minimum quench energy is greater for the high-C wire.

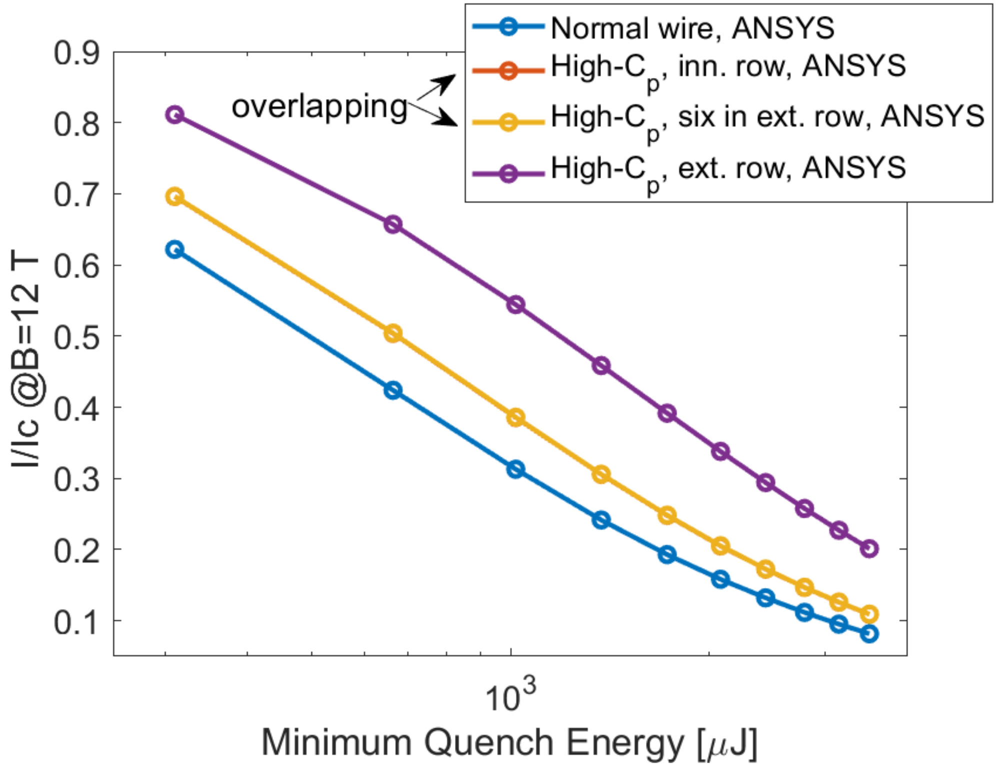
Is there an optimal thermal location for high-C elements?



High-C, inn.



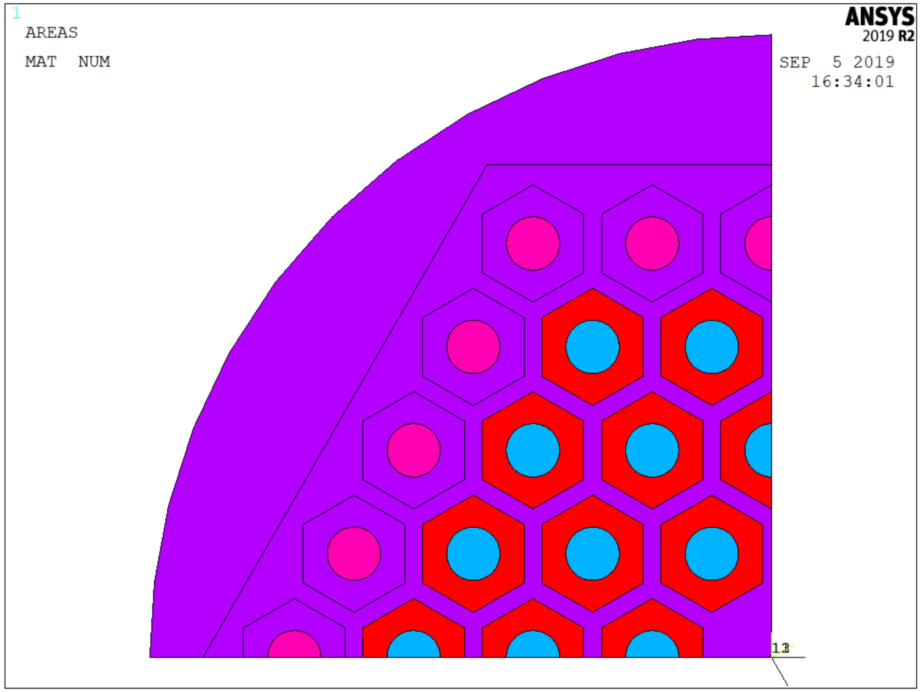
High-C, 3 ext.



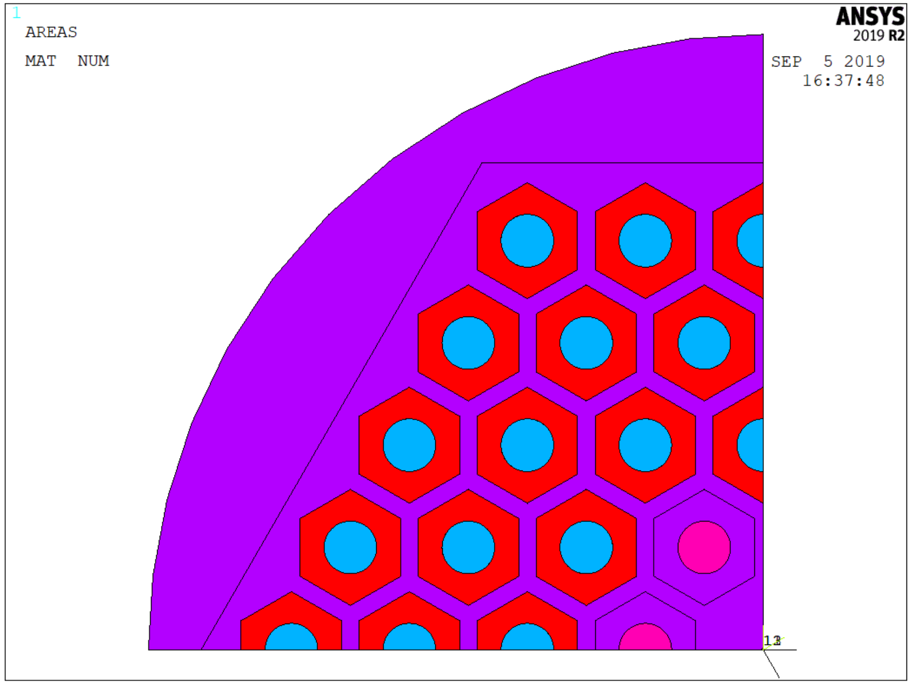
It is interesting to note that only the number of sub-elements counts.

Plastic simulation of wire drawing

from 0.75” to 0.71” diameter

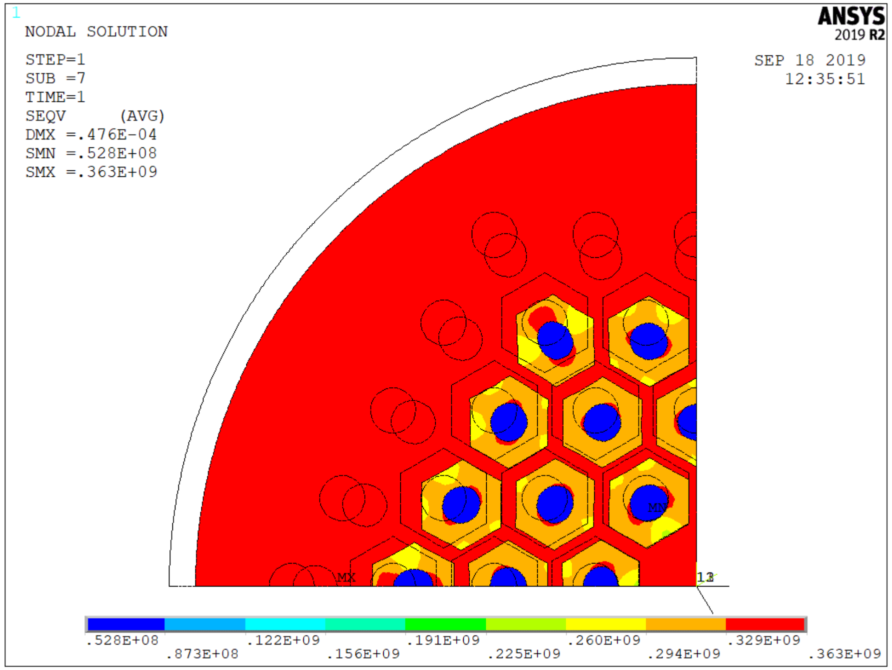


High-Cp elements in the outermost row



High-Cp elements in the innermost row

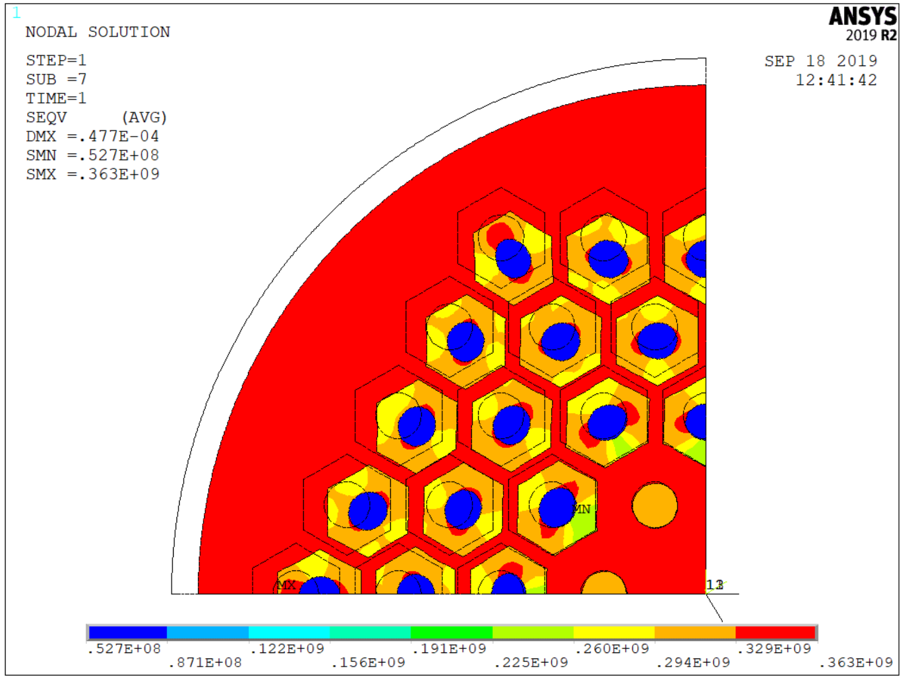
Plastic Analysis, 0.75” diameter



```
NODAL SOLUTION

STEP=1
SUB =7
TIME=1
SEQV       (AVG)
DMX =.476E-04
SMN =.528E+08
SMX =.363E+09
```

Von Mises Stress, 5% strain



```
NODAL SOLUTION

STEP=1
SUB =7
TIME=1
SEQV       (AVG)
DMX =.477E-04
SMN =.527E+08
SMX =.363E+09
```

Von Mises Stress, 5% strain

Conclusions

- The FEM thermal models give accurate ratio efficiency of the Gd_2O_3 sub-elements implementation according to experimental data [1] for higher currents. It is important to reproduce high-C area with respect to the wire cross-section.

- FEM structural models have been developed in order to develop structures that can be actually realized without drawing failure. Further analyses are required to find the right criterion.

- New MQE measurements are expected in the following days, to be compared with already existing FEM models.

Thank you for your attention.

REFERENCES

1) Xu X., Zlobin A.V. et al. “Development and Study of Nb_3Sn Wires With High Specific Heat.” IEEE, VOL. 29, NO. 5, AUGUST 2019

2) Barzi E.,Turrioni D., “Short sample limit calculation for 1 m long dipole MBHSP02 made of 150/169 RRP® strand and cored cable ” Fermilab, Batavia, IL, USA, Tech. Note, TD-00-041, 2000.